New pulsating variable stars in the Stock 14 open cluster and surrounding fields

D. Drobek[⋆]

Instytut Astronomiczny Uniwersytetu Wrocławskiego, Kopernika 11, 51-622 Wrocław, Poland

Received October 2012, accepted October 2012
Published online November 2012

Key words open clusters and associations: individual (Stock 14) – stars: oscillations – techniques: photometric

This paper presents the preliminary results of a multicolour photometric study of the young open cluster Stock 14 and adjacent fields. The reddening, distance and age of the cluster were determined from colour-colour and colour-magnitude diagrams by means of isochrone fitting. Fourier analysis of the acquired time-series data was performed, which resulted in the discovery of new pulsating variable stars and candidates for such objects.

1 Introduction

The young galactic open cluster Stock 14 is known to host two eclipsing binary systems with β Cephei-type pulsating components, HD 101497 and HD 101838 (Pigulski & Pojmański 2008). After the discovery of those systems the cluster was subject to a photometric follow-up study in order to confirm the finding (Drobek et al. 2010). The field of view of the telescope used for this follow-up encompassed the entire cluster and some adjacent regions of the sky. As a consequence, UBV time-series data of many objects in vicinity of the two program stars were acquired. This data set was well suited for a comprehensive variability survey in the observed field. No such study of the Stock 14 cluster has been conducted before. Because the observed field is located in the vicinity of the Galactic plane ($b \approx -0.7°$) and covers a part of the Cru OB1 association, one can expect to discover pulsating stars of early spectral types.

2 Observing run and data reduction

The photometric data used in this study were acquired by R. Shobbrook and A. Narwid during 19 nights between March and May 2007 with the 1.0-m telescope in Siding Spring Observatory, Australia. The detector being used was the Wide Field Imager, with a field of view of about 0.5 square degrees. The frames were calibrated using a standard procedure which consisted of overscan subtraction and trimming, bias subtraction, linearity correction and flat-fielding. Almost 25 000 stars were identified in the V-filter reference frame. The stellar magnitudes were calculated with the Daophot II software package (Stetson 1987). In order to remove the atmospheric effects from the resulting time series, differential photometry was used comparing to a set of stars which were evenly distributed in the observed field. The instrumental UBV magnitudes of each star were calculated as averages of its σ-clipped time series. Because no photometric standards were observed during the run, the transformation of instrumental magnitudes to the standard system was based on the photoelectric data of Peterson & FitzGerald (1988).

3 Cluster parameters

In this study, the number of stars with measured UBV colour indices is greater than in the works of Moffat & Vogt (1975), Turner (1985), Peterson & FitzGerald (1998) and Kharchenko et al. (2005) who previously determined the parameters of Stock 14. For this reason, an attempt to derive better values of cluster parameters was made. In order to reduce the number of field interlopers, a subset of stars located within 10 arc minutes from the centre of the cluster ($\alpha_{2000} = 11^{\rm h}43.6^{\rm m}$, $\delta_{2000} = -62°31'$) was selected.

The reddening of Stock 14 was estimated by fitting the relation between the intrinsic colours of the main sequence stars (Caldwell et al. 1993) to the colour-colour diagram of the cluster (Fig. 1). A standard relation between colour excesses, $E(U-B)/E(B-V) = 0.72$ was assumed. The reddening $E(B-V) = 0.20 \pm 0.02$ mag was derived. It should be noted that the reddened intrinsic colour relation does not fit equally well to all the stars in the plot. There is a discrepancy for stars with $(B-V)$ in the range from 0.2 to 0.5 mag. It seems to be caused by the difference between the standard and the instrumental U filters. This causes the $(U-B)$ colours to be unreliable for some stars. However, this does not affect the determination of reddening, as the intrinsic relation still fits the data very well in the regions occupied by stars of early and late spectral types.

The colour-magnitude diagram of the stars in the vicinity of the cluster (Figs. 2 and 3) shows a well-defined main

⋆ e-mail: drobek@astro.uni.wroc.pl

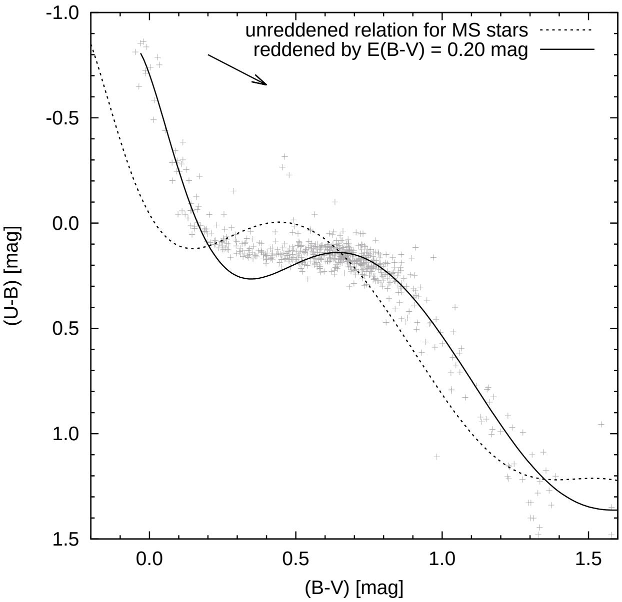

Fig. 1 Determination of the reddening of the Stock 14 cluster. Dashed line represents the unreddened relation, solid line represents the same relation reddened by $E(B-V) = 0.20$ mag. The arrow is a reddening vector corresponding to the derived colour excess.

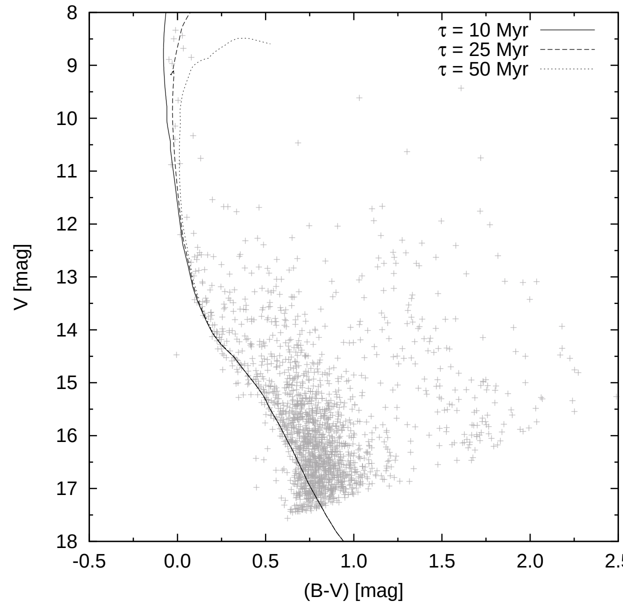

Fig. 2 Determination of the age and distance to the Stock 14 cluster. The best-fitting isochrone corresponds to the true distance modulus $(m-M)_0 = 11.63$ mag and the age $\tau = 25$ Myr. Solar metallicity was assumed, and the effects of rotation were not taken into account.

sequence down to V magnitude of about 15.5 mag. Once the reddening of Stock 14 was determined, the isochrones of Ekström et al. (2012) were fitted to the main sequence of the cluster in the colour-magnitude plane. Solar metallicity ($Z = 0.014$) was assumed. The results of fitting were similar regardless of including or neglecting the effects of stellar rotation on the isochrones. The true distance modulus was estimated at $(m-M)_0 = 11.63 \pm 0.05$ mag. The cluster seems to be between 10 and 50 Myr of age, with the best-fitting isochrone corresponding to $\tau = 25$ Myr. Since the previous estimates of the parameters of Stock 14 were based on smaller samples of stars, the results presented here should be regarded as more reliable.

4 Variable stars

With up to 1200 data points per star, the V-filter time series data were best suited for the variability survey. A discrete Fourier transform of every time series was calculated in the frequency range from 0 to 40 d^{-1}. In the resulting Fourier spectra the maxima with the signal-to-noise ratio above 4.0 were assumed to be significant. All of the resulting frequency spectra and light curves were examined by eye, and classified based on the available information, such as the shape of the light curve, frequencies, their corresponding light amplitudes, UBV colours, or spectral types found in the literature.

Out of the 92 new variable objects, 25 exhibit multiperiodic sinusoidal light variations. Detection of multiple independent frequencies usually indicates that light variations are caused by stellar pulsation. For this reason, all the discovered multiperiodic stars are assumed to be pulsating. Such assumption is not valid for the 19 monoperiodic variables, which are considered candidates for pulsating stars. Alternative explanations such as stellar rotation or ellipsoidal variability have to be taken into account. A summary of the numbers of discovered (candidate) pulsating stars and their corresponding variability classes is presented in Table 1.

Table 1 Summary of the discovered multiperiodic and monoperiodic pulsating variable stars and candidates.

Variability type	Multiperiodic (pulsating)	Monoperiodic (candidates)
β Cep	2	–
SPB	2	5
δ Sct	8	9
γ Dor / δ Sct	2	–
γ Dor	5	–
unknown	6	5

The positions of the discovered variable stars in the colour-magnitude diagrams are presented in two figures. In Fig. 3, only the stars located within 10 arc minutes from the centre of Stock 14 have been plotted. Because of the resultant reduction of the number of field stars, it is possible to distinguish a well-defined main sequence of the cluster. The two brightest β Cephei-type variables are the previously known pulsating stars in eclipsing binary systems, HD 101794 and HD 101838. They are shown here for the sake of completeness. In Fig. 4, the remaining stars from the observed field are shown. This plotted subset of stars is

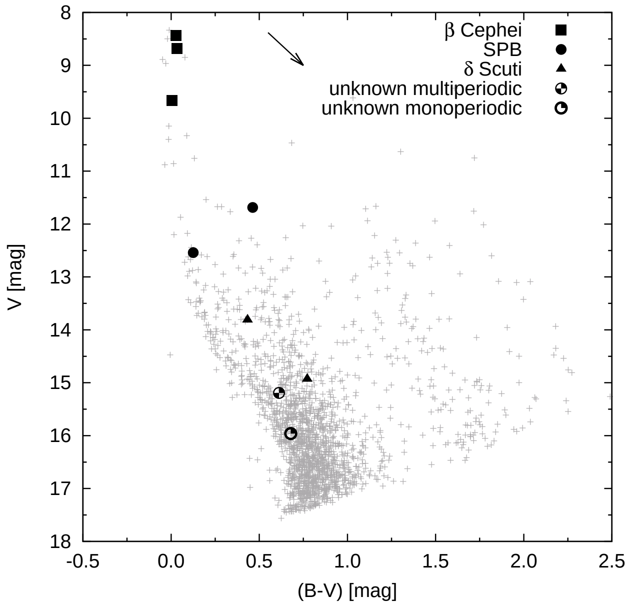

Fig. 3 Colour-magnitude diagram of the stars located up to 10 arc minutes from the centre of Stock 14. The symbols denote the discovered variable stars. The arrow is a reddening vector corresponding to $E(B-V) = 0.20$ mag.

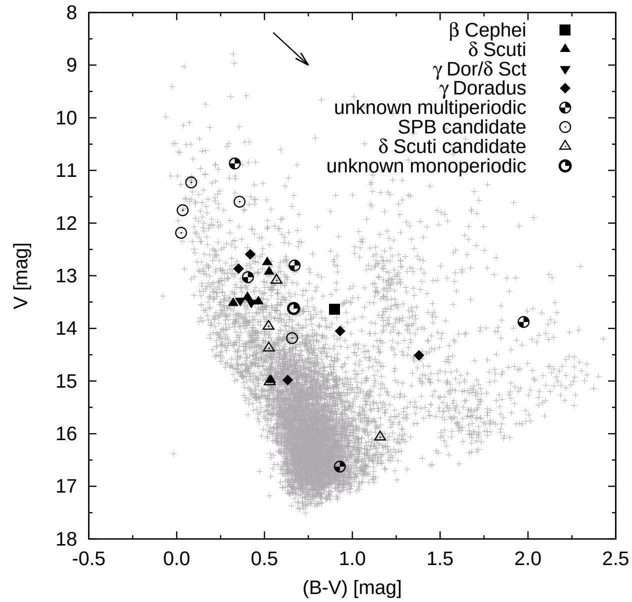

Fig. 4 Colour-magnitude diagram of the stars located further than 10 arc minutes from the centre of Stock 14. The meaning of symbols is similar to Fig. 3. The vast majority of the stars in this diagram are field objects.

a mixture of objets located at various distances from the Sun and reddened in a non-uniform manner. This can explain somewhat surprising positions of several variable stars in the colour-magnitude plane such as the β Cephei-type variable and one of the SPB candidates. Several of the 44 stars listed in Table 1 were very faint in B filter, which made their $(B-V)$ colour indices unreliable. Those stars are not shown in the colour-magnitude diagrams.

A detailed analysis of the properties of the discovered variable stars and their membership to Stock 14 is ongoing and will be published elsewhere. However, even after a cursory glance at the data it is safe to assume that the majority of the found variable objects are field stars not physically associated with the cluster.

5 Conclusions

The reddening and distance estimates show smaller reddening and smaller distance to Stock 14 in comparison to the results of Moffat & Vogt (1975), Turner (1985) and Peterson & FitzGerald (1998). On the other hand, they are in good agreement with the results of Kharchenko et al. (2005). The difference is likely caused by using a different intrinsic colour relation for main sequence stars as well as better quality of the photometric data and of the model isochrones.

Discovery of many pulsating stars and candidates for such objects is not surprising, taking into account that a dense field near the Galactic plane was observed. The majority of the new variable objects seem to be field stars not physically associated with Stock 14.

Acknowledgements. The author wishes to thank the Director of the Research School of Astronomy and Astrophysics of the Australian National University for time on the 40-inch telescope at Siding Spring Observatory. This research has made use of the WEBDA database, operated at the Institute for Astronomy of the University of Vienna, the Vizier catalogue access tool, CDS, Strasbourg, France and the SAOImage DS9, developed by Smithsonian Astrophysical Observatory. This work was supported by the National Science Centre grant No. 2011/01/N/ST9/00400.

References

Caldwell, J.A.R. et al.: 1993, SAAOC 15, 1
Drobek, D. et al.: 2010, AN 331, 1077
Ekström, S. et al.: 2012, A&A 537, 146
Kharchenko, N.V. et al.: 2005, A&A 438, 1163
Moffat, A.F.J. & Vogt, N.: 1975, A&AS 20, 125
Peterson, C.J. & FitzGerald, M.P.: 1988, MNRAS 235, 1439
Pigulski, A. & Pojmański, G.: 2008, A&A 477, 917
Stetson, P.B.: 1987, PASP 99, 191
Turner, D.G.: 1985, PASP 94, 655